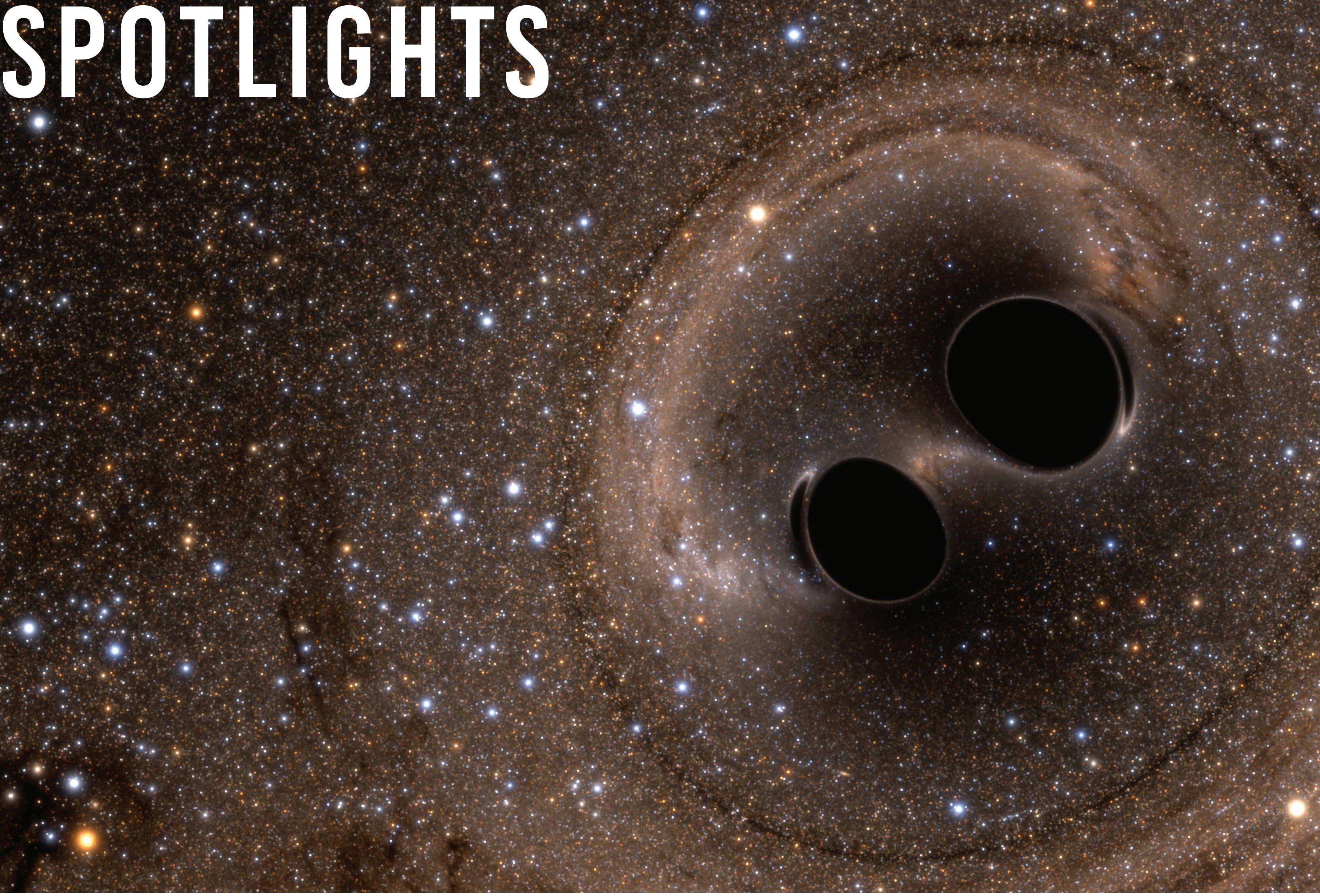
SPOTLIGHTS



Ripples in Space and Time

WHEN THE DISCOVERY OF GRAVITATIONAL WAVES from a cosmic black-hole collision was announced earlier this year, the scientific community was absolutely abuzz. Not only was it a tremendous achievement for the Laser Interferometer Gravitational-wave Observatory (LIGO)—first approved 26 years ago and under construction or operating with no confirmed detections until now—but it was also the first-ever direct measurement of gravitational waves, whose existence Einstein predicted with his theory of spacetime exactly 100 years ago.

The discovery also confirmed a Los Alamos prediction from 2010: based on the population statistics of objects capable of producing detectable gravitational waves, the most likely event for discovery would be the merger of two black holes. Because of the extreme gravity of black holes, their collision dramatically distorts the fabric of the universe, producing ripples in spacetime that, upon reaching Earth, minutely alter the distance traveled by each four-kilometer-long laser beam in LIGO's ultrasensitive interferometers. Making such a delicate observation is groundbreaking to be sure, but Los Alamos astrophysicist Chris Fryer says it's only the beginning.

"The detection LIGO announced is actually one of three strong signals currently in their rumor mill," Fryer says. "We may soon begin to obtain detections in quantities that allow us to do new kinds of studies on the prevalence of such mergers in the galaxy." Indeed, Fryer and his collaborators recently calculated the distribution of black hole masses likely to be found in binary systems that could produce observable merger events. They based these calculations on the types of stars that form black holes when they go supernova and the force with which the black holes are propelled by their violent birth. All three potential detections to date conform to his mass predictions.

Yet much of the excitement of gravitational-wave astronomy may not center upon black holes at all. Another highly compact object with extreme gravity, also formed when massive stars go supernova, is known as a neutron star and can merge with either black holes or with other neutron stars. Such neutron-star-on-neutron-star mergers are the main focus of Fryer's research. They allow him to examine the rich physics at work in extreme environments inaccessible to Earth-bound laboratories—physics that may be responsible for the very existence of certain natural elements found on Earth.

Middleweight metals like iron, the 26th element, are made by nuclear fusion of lighter elements inside stars. But making much heavier metals like platinum or gold (numbers 78 and 79, respectively) requires higher-energy processes that combine explosive conditions with an abundance of neutrons. Astrophysicists have long reasoned that supernova explosions could be the source of those processes, but supernova simulations have difficulty reproducing robust signatures in the element-abundance data. Instead, they show that precious metals and other heavy elements are unlikely to emerge in significant quantities.

In a binary black-hole system, the black holes spiral inward and eventually merge into one, emitting gravitational waves in the process. Observations of this process were reported for the first time earlier this year.
CREDIT: Simulating eXtreme Spacetimes (SXS) project

However, according to recent computer simulations, those elements would be ejected en masse during neutron-star mergers. New research even suggests that a nearby neutron-star merger that took place shortly before the formation of our solar system may have gifted our future planet with a modest excess of these valuable elements. Then the two neutron stars combined into a single black hole that has since wandered away across the galaxy.

Fryer believes there is much to learn from neutron-star mergers and their gravitational-wave emissions in terms of the evolving population of black holes, production of heavy metals, and extreme physics. He is currently working to identify observable events that would sharpen human understanding of the unobservable structure and dynamics of neutron-star interiors. He is also preparing to use merger statistics, as they roll in, to help resolve a longstanding ambiguity concerning the cutoff mass above which stars are destined to become black holes instead of neutron stars. His recent publications lay the groundwork for these advances.

But beyond pure science, Fryer's research is a matter of national security. In addition to neutron-star collisions likely being the ultimate supplier of key national-security materials, including uranium, their explosive nuclear dynamics are applicable to nuclear-weapons research. And many of the Los Alamos scientists who work with Fryer on astrophysical problems subsequently join him and others on essential national-security computations as well. LDRD

— Craig Tyler

Small Fusion Could Be Huge

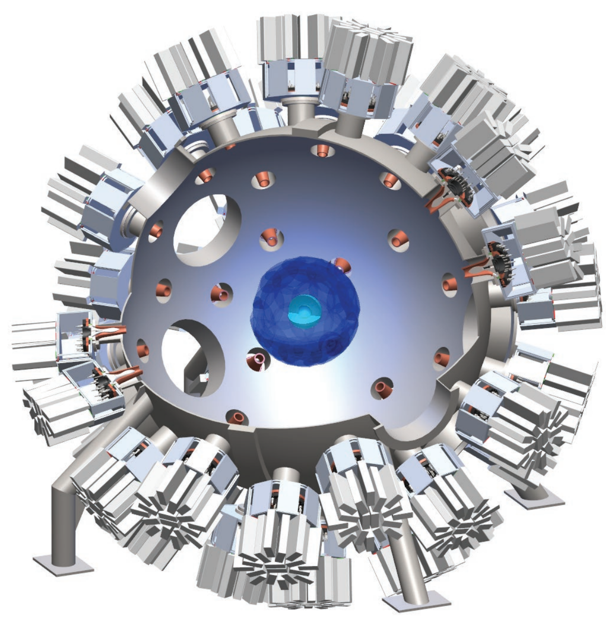
COMMERCIAL POWER FROM NUCLEAR FUSION is 30 years away. We know this because the fusion-energy research community has been saying so for 50 years.

If fusion energy ultimately works, its benefit to humankind is virtually impossible to overstate. The nuclear energy release is about four million times greater than the chemical energy released by burning coal, oil, or natural gas, and for that reason it requires very little fuel. Sixty kilograms of fusion fuel—which one strong person could physically carry into the power plant—would power a city of a million for a year. It would take 400,000 metric tons of coal to do the same. On top of that, the fusion reaction produces no carbon emissions, nor any other pollutant.

The reaction works by joining, or fusing, nuclei of hydrogen-2 (or deuterium) and hydrogen-3 (tritium) together to make helium-4 (a harmless and useful gas) plus a neutron, which then interacts with lithium in a way that "breeds" tritium for subsequent fusion reactions. The inputs, deuterium and lithium, are both present in seawater in quantities that would last millions of years at least.

The world's grandest fusion project to date is an international collaboration called ITER that comprises a massive reactor under construction in France. Once finished, it will be an experimental platform for demonstrating a sustained fusion reaction that generates more power than it consumes, similar to what goes on at the core of the sun. It was originally scheduled to come online this year at a cost of $12 billion, but its director-general recently stated that it would not be finished before 2025—and for no less than $20 billion—producing a net energy gain no earlier than 2035. The U.S. share alone is now expected to grow from $1.1 billion to closer to $5 billion. And that's just for a fusion *experiment*—the precursor to an actual power plant.

While ITER is a major step toward proving the feasibility of fusion, many scientists and energy-policy experts believe it is important to



Cutaway view of an imploding plasma liner (blue), formed by 60 inward-directed plasma jets, as it engages a magnetized plasma fuel target. (Plasma is hot, ionized gas.)